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SLOPE STABILITY STUDY OF THE REGIONAL MUNICIPALITY OF OTTAWA-CARLETON ONTARIO CANADA

by

M.A.Klugman and P.Chung

1976

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SLOPE STABILITY STUDY OF THE REGIONAL MUNICIPALITY OF OTTAWA-CARLETON, ONTARIO, CANADA

by

M.A. Klugman[1] and P. Chung[2]

INTRODUCTION

The St. Lawrence River Valley and the Ottawa River Valley, which include much of eastern Ontario, have extensive deposits of glacially derived marine clays that were laid down in the Champlain Sea.

Most of the area of the Regional Municipality of Ottawa-Carleton is underlain by these unconsolidated sediments and their subsequently reworked derivatives. These clays exhibit unique characteristics for which they are termed 'quick clays' or 'sensitive clays'. Because of their unusual characteristics, these clays are prone to landslide activity. Landslides are common along stream banks and terraces in the Ottawa area and, as a result, adversely affect planning, development, and construction activities. Every slope higher than 10 feet or with a grade of 1:4 or more should be examined for stability. This study is a guide to aid the Province and the Municipalities, and other authorities, planners, and developers in knowing when to obtain expert assistance at a very early stage in a development.

The need to establish guidelines for planning and development in the Regional Municipality of Ottawa-Carleton was recognized by the Planning Department of the Municipality and by the Eastern Region of the Ontario Ministry of Natural Resources. As a result, a program to classify the slopes in the unconsolidated deposits in the Municipality was undertaken by the Ontario Ministry of Natural Resources in collaboration with the Planning Department of the Municipality. The field program was funded by the Regional Municipality of Ottawa-Carleton.

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GEOLOGICAL BACKGROUND

The geologic history of the Champlain Sea and the surficial geology of eastern Ontario has been well documented by Gadd, Karrow, Richard, and others (Gadd 1963; 1971; 1975; Karrow 1961; Minning 1972; Richard 1974a, b; and 6 maps in preparation).

During and following the fluctuating withdrawal of the Laurentide ice of Wisconsin Age, approximately 13,000 years ago (Richard 1974a), the St. Lawrence Lowlands, the Ottawa River Valley, and much of eastern Ontario was submerged beneath the Champlain Sea. During this period, extensive deposits of marine clay were laid down. The deposition took place under continually decreasing saline concentrations (Elson 1969), until about 10,000 years ago. Subsequent erosion, reworking, and redeposition of some of these marine clays in a fresh water environment also took place; this could have been caused by the draining of the fresh water Lake Barlow-Ojibway into the Ottawa Valley from the west (Gadd 1963; 1975).

The mineralogic composition of the Champlain Sea clays is diverse, with the percentage of the constituent minerals varying considerably from location to location. Extensive studies, current and past, have been undertaken at specific localities, usually where a landslide has occurred (Allen and Johns 1960; LaRochelle 1972; LaRochelle *et al.* 1970; Loiselle *et al.* 1971; Rochette 1956; Sangrey and Townsend 1969; Wong *et al.* 1974; this represents only a part list of references).

The most common mineral constituents of the Champlain Sea clays are quartz and feldspar flour, illite, vermiculite, montmorillonite, chlorite, and carbonate minerals in diverse amounts.

The stratigraphy of the clays is not uniform because of the changing depositional environment during the recession of the ice front.

As a result, horizons of coarser sediments, silt, sand, and gravel, occur above, below, and within the stratigraphic section. Due to their permeability, these horizons may contribute to high water-table conditions in the sections, resulting in high pore water pressures in certain outcrops.

In summary, these marine deposits were derived from glacial outwash and, in the final stage, from the erosion of these glacial deposits as the ice front retreated. They were deposited under marine and estuarine conditions in an initially saline environment, which decreased in salinity as the Champlain Sea regressed.

SLOPE FAILURE

Many slope failures occur in the Ottawa area every year. These usually take the form of small rotational slips which commonly retrogress. They are capable of retrogressing considerable distances into the slopes. In places, these retrogressive slides become large earthflows.

Considerable work has been undertaken in the study of the behaviour of sensitive marine clays, particularly with reference to landsliding and slope failures. Of particular significance to this study are the studies carried out in the Ottawa area by Crawford, Eden, Mitchell, Jarrett, Paul, Sangrey, and others (Crawford 1968; Eden and Jarrett 1971; Eden and Mitchell 1970; 1973; Jarrett and Eden 1970; Mitchell 1970; Mitchell and Eden 1972; Mitchell and Markell 1974; Paul 1970; and Sangrey and Paul 1971).

The principal factors affecting the stability of all slopes are: the height of the slope; the inclination; the nature of the soil material and its properties; the ground water pressures in the soil, and the local stratigraphy and structure, such as its stratigraphic section, dip of beds, facies changes, and planes of weakness.

Oversteepening is the principal cause of landslides. Commonly slopes will become oversteepened and remain apparently stable until certain conditions exist to cause failure. Oversteepening can come about by natural causes, such as erosion; or by the activities of man, such as grading, construction, or diversion of stream flow. Another important factor affecting the stability of slopes in the Ottawa area is the sensitivity of the clay, being defined as the ratio of its undisturbed strength to its remoulded strength at the natural water content; the higher the sensitivity of the clay, the greater the loss of strength when disturbed. Most failures occur in the Ottawa area in spring and fall when ground is water saturated. This causes a reduction in shear resistance and thus failure may occur.

The large retrogressive earthflows in the Ottawa area have been mapped by the Geological Survey of Canada and, with their permission, are incorporated into the maps of the Regional Municipality accompanying this report. The principal concern of this study is to delineate the areas of potential failure, and the relatively small simple slip and retrogressive rotational slide scars. A few small earthflow slides were also observed and mapped in this survey.

It is stressed that the responsible authorities should ensure that any area slated for development is safe from possible slope failures or landslides. In this context the prime concern of this study is the relatively small landslide, or failure, which can be measured in terms of a few thousand cubic yards of material, or up to a few acres in size. It is these failures that occur every year, commonly in the same place, or adjacent to an old failure, which can cause considerable local distress. Every slope higher than 10 feet or with a grade of 1:4 or more should be examined for stability.

FIELD PROGRAM

The completed field program was carried out from May 5th, 1975 to September 2nd, 1975. All creek and river banks were examined as well as terraces and slopes in the Regional Municipality. Bedrock scarps and rock-defended slopes were not included in the survey. Where there was some question as to whether a slope was rock-defended, it was carefully examined in order not to exclude possibly unstable slopes.

All slope failures and landslide scars were recorded where recognizable. The large earthflows had previously been mapped by the Geological Survey of Canada, and after field checking, these data were incorporated into the maps of this report (Maps 2374, 2375, 2376, 2377, and 2378, back pocket).

Air Photographs

The scale of the air photographs used in the field was 1:25,000. These were supplemented by 1:5,000 scale air photographs, in the office, to check detail. It was found that

for the purposes of this survey, the 1:25,000 scale air photographs were adequate, but that future studies should utilize a larger scale, such as 1:12,500, in order to increase the efficiency of the field program.

Before going to the field each area was carefully examined in stereoscopic pairs and all slope features were noted. Overlays were attached to alternate photographs and were marked with pertinent features, control lines, fieldbook number, and the photograph number. These overlays were used to record the locations of the slope survey sites being measured in the field, as well as other features such as landslide scars.

Slope Measurement

Slopes less than 10 feet high were not measured unless the slope inclination was in excess of 25 degrees. Slope measurements were taken at all sites where considered necessary, and their locations accurately marked on the overlays of the air photographs. Slope angles were measured by clinometer and pocket transit. Due to the irregularity of some slope surfaces, angles were measured to the nearest two degrees and slope heights were measured as accurately as possible, with a maximum allowable error of 2.5 feet in slopes exceeding 25 feet in height. These data were then recorded in the fieldbook.

At sites where landslides or slope failures had occurred, the width, length, and height of the back scarp were measured and recorded. For the purpose of this study, it was necessary to know the configuration of the slope prior to its failure. Since it was not possible to measure the original slope, the slope immediately adjacent to the failure was measured to determine the present 'Factor of Safety' for that specific site. These data were plotted on a 1:25,000 scale field base map and subsequently transposed, after computation of the 'Factors of Safety', to the final map on a scale of 1:50,000.

Landslides were categorized into the following types: earthflows, rotational slides, sheet slides, and failing slopes. Where failures were too small for exact recording, each type was plotted by symbol on the base map.

COMPUTER PROGRAM

A computer program developed at the National Research Council by J.G. Arseneault (1967) was adapted by R.J. Mitchell of Queen's University, Kingston, Ontario, for analyzing the data in this study. The program has been modified so that a variable r_u factor and variable densities (unit weights) can be input for non-homogeneous soils (layered systems) and non-homogeneous ground water conditions.

The program was used to solve for the Factor of Safety of slopes under given conditions. Each slope, in this study, was approximated by three line segments, with the computer program also being used to allow for later input of additional line segments for detailed 'site-specific' studies where necessary. All slopes were resolved into a co-ordinate system. The toe point was chosen for the failure point where the slip circles would pass through. The centres of 100 slip circles were located by the computer inside a search area to find the minimum Factor of Safety and critical centre. The search area was bounded by the co-ordinates: X_s (over the middle of the slope); X_f (over the toe point); Y_s (height of slope); Y_f (f times the height).

No soil parameters were determined in this field survey. Ground-water conditions typical of spring (e.g. hydrostatic saturation of the slopes) were used in these calculations. To obtain ϕ' (effective angle of internal friction) and c' (effective cohesion) values, an average of 33° and 200 pounds per square foot were used for conditions of low confining pressure, such as are present in the shallow failures in the Ottawa area. Table 1 shows some values for ϕ', c', and r_u obtained from site-specific studies in the Ottawa area.

These average values were checked against soil parameters determined by previous workers in site-specific studies in the vicinity of survey points throughout the area. These data were obtained prinicpally from publications by personnel of the National Research Council and their associated workers, from soils reports of the Ministry of Transportation and Communication, and from consultants' reports throughout the area. The review of these data showed that ϕ' and c' values used were realistic for establishing a semi-quantitative guideline classification as used in this report. As a precaution against over-simplification, a range of safety factors for each condition was also

TABLE 1 SOME VALUES FOR 'EFFECTIVE ANGLE OF INTERNAL FRICTION ϕ'', 'EFFECTIVE COHESION c'' AND 'PORE PRESSURE r_u' OBTAINED FROM SITE-SPECIFIC STUDIES IN THE OTTAWA AREA.

Slope	Critical Strength Parameters c' (psf)	ϕ'(deg.)	r_u	Remarks	Source
Green Creek	204	36°	0.60	Assumed Hydrostatic Saturation	Mitchell and Eden 1972
Bilberry Creek	200	32°	0.62	Assumed Hydrostatic Saturation	Golder Assoc. 1975
Queenswood	225	33°	0.62	Assumed Hydrostatic Saturation	Golder Assoc. 1974
Rockcliffe	189	36.8°	0.62	Assumed Hydrostatic Saturation	Paul 1970
Rockcliffe	245	33°	0.62	Hydrostatic Saturation Indicated	Mitchell 1970
Orleans	224	34.5°	0.59	Assumed Hydrostatic Saturation	Eden and Jarrett 1971

calculated for ϕ' values of 30° and 35°. It was found that these two conditions did not significantly affect the segments of the classification.

Given input data used was:

c' - effective cohesion in lb/ft^2 = 200 psf
ϕ' - effective angle of internal friction in degrees = 33°
γ - unit weight of soil in lb/ft^3 = 100 pcf
r_u - pore pressure ratio = 0.62

The input data cards were arranged as follows:

Card 1 - 04 - Slope number
Card 2 - 03 - Number of line segments of slope (N)
Card 3 - x y
Card 4 - x y
Card 5 - x y
Card 6 - x y
Co-ordinates of nodes of line segments in consecutive order (to a maximum of 20)
Card 7 - 1.00 200 - FS and c'
Card 8 - 10 - Constant γ, other than 10 means variable
Card 9 - 100.0 - γ
Card 10 - 10 - For constant r_u
Card 11 - 0.62 - r_u
Card 12 - 33 - ϕ' (in degrees)
Card 13 - 30 35 - Other trial values of ϕ' for minimum FS
Card 14 - X_s X_f - X co-ordinates for search area for critical centres
Card 15 - Y_s Y_f - Y co-ordinates for search area for critical centres
Card 16 - X Y - X,Y co-ordinates of chosen failure point
Card 17 - Blank - Terminates readings and directs program to next slope number

Figure 1 shows the relationships of slope inclinations and slope heights to Factors of Safety obtained from the results of the survey in the Ottawa area. This graph can be used as a rough guide for determining the Factor of Safety in the Ottawa area.

Figure 2 shows the computed parabolic relationship of the Factors of Safety of 1.0 and 1.5 to a plot of slope inclination versus height of slope. Also plotted are the field data showing failed and unfailed slopes, for 419 stations of the 532 surveyed sites.

Each site surveyed in the Regional Municiaplity of Ottawa-Carleton is shown on the accompanying Maps 2374, 2375, 2376, 2377, and 2378 (back pocket); each site is identified by a slope number. Symbols on the accompanying maps which do not have a number are the locations of slope failures only. Either readings could not be taken or, at the discretion of the surveyor, were not taken at these locations.

Table 2 gives the computed Factor of Safety for all sites surveyed. These values are time dependant for the field conditions at the time the data was recorded. The values should not be used for detailed site design. It should be stressed that they are presented solely as a guide to further planning work.

SLOPE CLASSIFICATION

Based upon the computed Factors of Safety, the slopes have been grouped into six classes. The specific values used in the classification are presented as a guide to the slope conditions and not as a firm basis for engineering design or development. Under all circumstances, site-specific studies and/or inspections should be carried out at all sites before any planning or development is undertaken.

A dual classification is given for each of the six classes of slope. One is a numerical value based on the calculated factors of safety, and the second is a parallel corresponding verbal description for each class.

SLOPE STABILITY CLASSIFICATIONS

Factor of Safety	Guidelines
< 0.8	Unsuitable for construction, or will require extreme remedial measures in order to safely utilize the site. These measures would need to be based upon extensive detailed geotechnical studies. The proportion of necessary investment to make the property usable for construction would far outweigh the cost of the completed structures. It is therefore not economically feasible.
0.8 - 1.2	Will require extensive remedial measures as dictated by detailed geotechnical studies. The necessary investment to prepare and stabilize the site will be great and would make normal development uneconomic.
1.2 - 1.5	Detailed geotechnical investigation necessary, with concomitant remedial works. This class, under undisturbed conditions, is considered marginal. Stabilization works or restrictive physical conditions would be necessary. Their type and extent would depend on the type of development.
1.5 - 2.0	Routine geotechnical investigation necessary. Developer would have to know soil conditions. Stabilization works would depend on type and size of planned structures.
2.0 - 2.5	Routine inspection necessary to determine the need and extent of geotechnical investigation.
> 2.5	Should be inspected, but no remedial action likely to be required. This class also includes slopes that were inspected but, because of their nature, no detailed recordings were deemed necessary.

ACKNOWLEDGEMENTS

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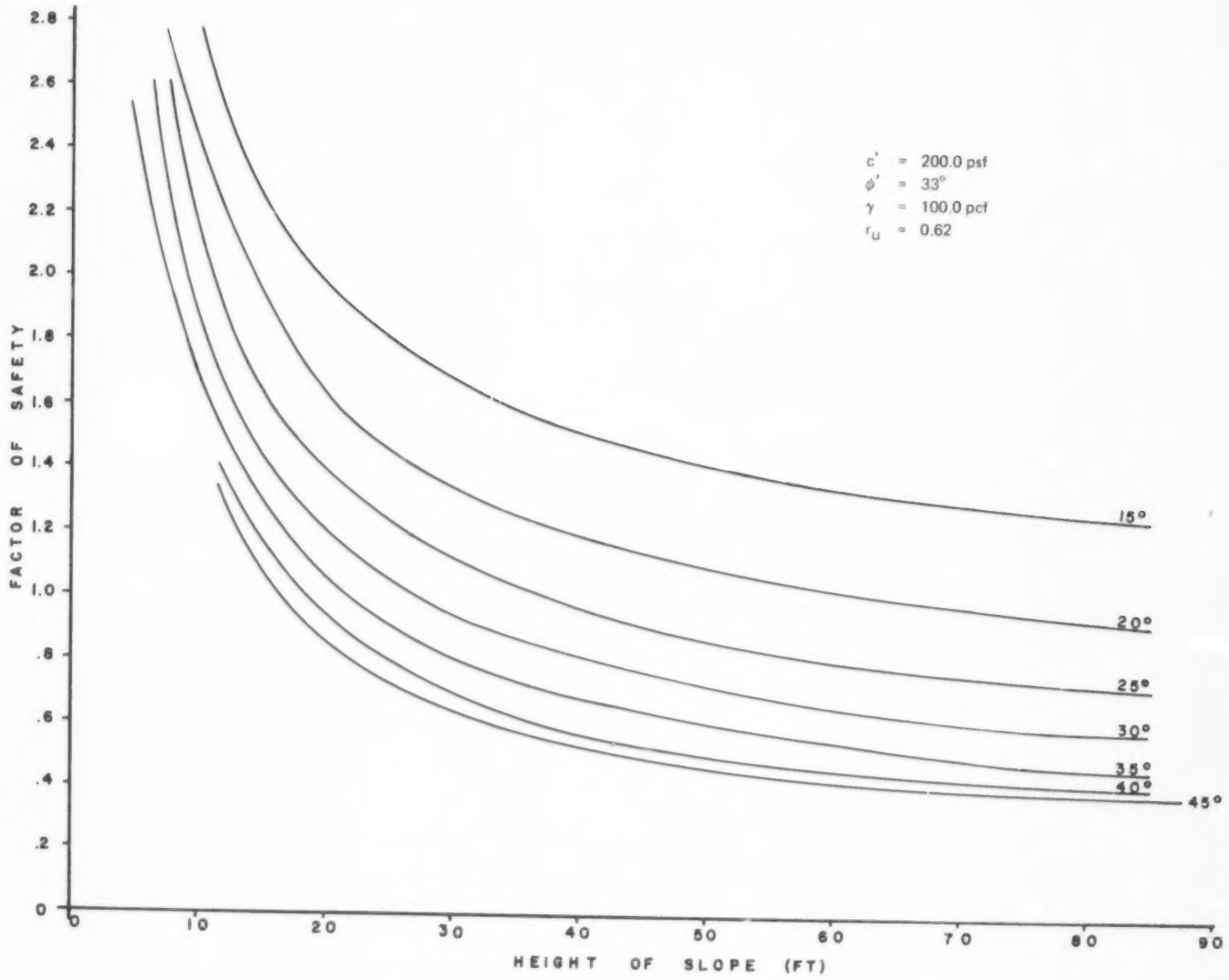

Figure 1 – Showing the relationships between the slope inclinations, the slope heights, and the Factors of Safety as computed for this study in the Ottawa area.

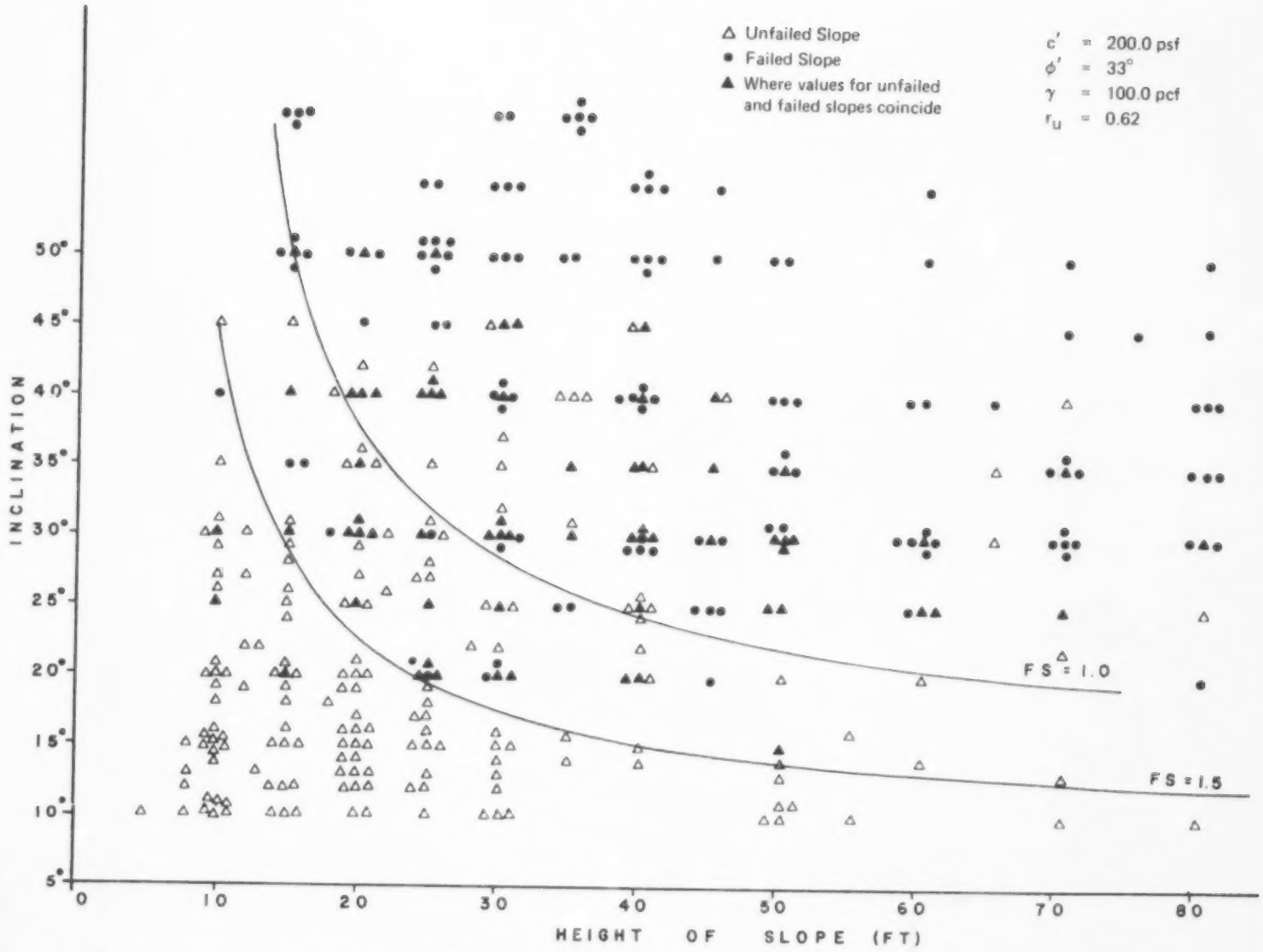

Figure 2 – Showing the calculated curves of Factors of Safety of 1.0 and 1.5, and their relationship to 419 surveyed points in the field. This also illustrates the unfailed versus the failed slopes.

TABLE 2 COMPUTED FACTORS OF SAFETY FOR SURVEYED SITES IN THE OTTAWA-CARLETON AREA.

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
1	0.87	51	0.88	101	0.80	151	1.89	201	1.21	251	1.89
2	1.68	52	0.88	102	0.94	152	0.97	202	0.54	252	1.89
3	1.40	53	0.94	103	2.26	153	0.95	203	0.88	253	1.89
4	1.25	54	0.60	104	2.26	154	0.62	204	1.71	254	1.89
5	1.43	55	0.94	105	1.44	155	0.62	205	1.21	255	2.78
6	1.35	56	0.62	106	1.44	156	0.57	206	0.81	256	2.15
7	1.03	57	0.62	107	1.44	157	1.30	207	0.85	257	2.43
8	0.72	58	0.59	108	1.02	158	1.44	208	0.81	258	2.43
9	1.19	59	0.59	109	2.43	159	0.94	209	1.00	259	3.00
10	0.70	60	0.49	110	0.70	160	1.05	210	1.00	260	3.20
11	1.46	61	0.52	111	0.53	161	0.70	211	1.21	261	3.50
12	1.19	62	0.70	112	0.81	162	1.02	212	1.64	262	2.70
13	1.12	63	0.46	113	0.56	163	0.80	213	1.99	263	1.63
14	1.45	64	0.42	114	0.52	164	0.74	214	1.95	264	2.80
15	0.53	65	0.42	115	0.58	165	0.53	215	2.05	265	2.80
16	2.50	66	0.46	116	1.46	166	1.21	216	2.43	266	1.99
17	1.99	67	0.73	117	1.81	167	1.21	217	2.20	267	1.71
18	0.91	68	0.94	118	0.69	168	1.21	218	>2.50	268	1.89
19	1.13	69	0.47	119	0.47	169	0.59	219	2.26	269	1.55
20	0.91	70	0.43	120	0.46	170	0.94	220	1.63	270	2.43
21	1.15	71	0.40	121	0.49	171	0.81	221	>2.50	271	2.15
22	1.03	72	0.53	122	0.52	172	0.87	222	1.46	272	1.44
23	1.19	73	0.82	123	0.39	173	0.77	223	1.46	273	2.78
24	1.46	74	0.63	124	0.70	174	0.77	224	1.97	274	0.44
25	0.62	75	0.62	125	0.57	175	0.50	225	1.97	275	0.66
26	0.54	76	0.63	126	0.39	176	0.73	226	2.78	276	0.42
27	0.91	77	0.52	127	0.39	177	1.19	227	3.20	277	0.62
28	1.19	78	0.50	128	0.70	178	1.89	228	2.80	278	0.51
29	0.70	79	0.52	129	0.61	179	1.23	229	3.20	279	0.64
30	0.66	80	0.59	130	0.66	180	1.06	230	2.60	280	0.88
31	1.35	81	0.60	131	0.50	181	0.70	231	1.13	281	0.58
32	0.62	82	0.52	132	0.47	182	0.94	232	1.13	282	1.03
33	1.40	83	0.60	133	0.61	183	2.35	233	2.78	283	0.77
34	0.72	84	0.59	134	0.62	184	2.35	234	2.78	284	0.73
35	1.05	85	0.52	135	0.91	185	2.06	235	1.85	285	0.73
36	0.82	86	0.50	136	0.81	186	2.00	236	1.95	286	0.77
37	0.87	87	0.42	137	0.70	187	1.07	237	1.95	287	0.77
38	2.00	88	0.66	138	0.77	188	0.88	238	2.20	288	1.81
39	0.82	89	1.21	139	1.21	189	1.50	239	1.95	289	1.46
40	2.26	90	1.05	140	1.21	190	1.06	240	3.20	290	0.80
41	2.60	91	1.39	141	0.70	191	0.63	241	1.97	291	0.88
42	0.87	92	1.02	142	0.81	192	1.44	242	3.20	292	0.39
43	1.81	93	1.30	143	0.94	193	1.06	243	2.40	293	0.73
44	1.45	94	0.94	144	0.94	194	0.78	244	3.20	294	0.50
45	1.13	95	0.69	145	1.02	195	0.55	245	3.20	295	1.19
46	1.26	96	0.56	146	0.57	196	0.80	246	2.15	296	0.73
47	1.13	97	0.62	147	0.56	197	1.05	247	2.15	297	1.19
48	1.13	98	0.70	148	0.70	198	1.05	248	2.15	298	0.82
49	0.70	99	0.60	149	0.94	199	0.80	249	2.15	299	0.82
50	0.57	100	0.60	150	1.21	200	1.06	250	1.97	300	0.88

Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS	Site No.	FS
301	0.58	351	0.82	401	0.82	451	0.97	501	1.62
302	0.82	352	0.54	402	0.95	452	2.55	502	>2.50
303	3.20	353	0.69	403	0.73	453	2.10	503	1.22
304	4.00	354	0.73	404	0.95	454	0.97	504	1.62
305	3.20	355	0.69	405	0.58	455	1.42	505	1.78
306	2.80	356	0.58	406	0.53	456	1.91	506	2.00
307	1.70	357	0.58	407	>2.50	457	1.35	507	1.98
308	1.70	358	0.63	408	>2.50	458	1.97	508	1.95
309	0.91	359	0.58	409	2.08	459	1.42	509	1.70
310	0.72	360	0.69	410	2.07	460	1.85	510	1.20
311	0.63	361	1.05	411	2.07	461	0.97	511	1.20
312	3.50	362	1.97	412	2.00	462	2.05	512	1.90
313	1.39	363	0.80	413	1.64	463	2.00	513	>2.50
314	1.23	364	0.65	414	1.68	464	1.65	514	>2.50
315	flow	365	0.82	415	1.57	465	1.63	515	>2.50
316	0.87	366	0.95	416	1.74	466	1.97	516	1.78
317	0.81	367	0.82	417	2.45	467	2.00	517	1.20
318	0.66	368	0.46	418	2.15	468	1.63	518	1.47
319	0.73	369	0.69	419	1.81	469	2.20	519	1.62
320	0.61	370	1.39	420	1.97	470	>2.50	520	1.48
321	flow	371	1.39	421	2.15	471	2.28	521	1.48
322	0.66	372	1.05	422	1.97	472	1.33	522	>2.50
323	0.87	373	1.23	423	2.40	473	2.00	523	1.82
324	0.50	374	1.39	424	1.55	474	>2.50	524	2.30
325	0.61	375	0.52	425	1.63	475	>2.50	525	1.68
326	0.77	376	0.82	426	1.71	476	2.25	526	>2.50
327	2.78	377	0.66	427	0.91	477	1.63	527	>2.50
328	3.80	378	0.73	428	1.55	478	2.26	528	>2.50
329	2.26	379	0.77	429	1.17	479	2.43	529	>2.50
330	3.20	380	0.73	430	1.17	480	1.61	530	1.42
331	>2.50	381	0.58	431	0.97	481	1.61	531	1.62
332	>2.50	382	0.70	432	1.14	482	1.61	532	1.68
333	1.70	383	0.70	433	0.81	483	1.85		
334	>2.50	384	0.69	434	1.42	484	1.81		
335	>2.50	385	1.46	435	2.26	485	2.05		
336	2.78	386	2.78	436	1.39	486	1.68		
337	2.90	387	2.78	437	>2.50	487	>2.50		
338	2.78	388	2.43	438	2.05	488	2.26		
339	3.20	389	1.97	439	>2.50	489	1.95		
340	3.50	390	1.63	440	>2.50	490	2.15		
341	1.05	391	2.78	441	2.78	491	2.05		
342	1.12	392	1.99	442	1.23	492	1.89		
343	1.06	393	1.46	443	1.35	493	2.00		
344	0.87	394	1.97	444	0.73	494	1.84		
345	0.80	395	2.78	445	1.97	495	2.43		
346	1.28	396	2.78	446	2.78	496	1.97		
347	1.60	397	0.95	447	>2.50	497	1.15		
348	2.78	398	0.82	448	2.78	498	1.40		
349	1.60	399	0.95	449	2.00	499	1.35		
350	1.18	400	0.46	450	2.05	500	1.68		

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